BS EN 13001-3-3:2014

BSI Standards Publication

Cranes - General design

Part 3-3: Limit states and proof of competence of wheel/rail contacts

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National foreword

This British Standard is the UK implementation of EN 13001-3-3:2014. Together with BS EN 13001-1:2004+A1:2009, BS EN 13001-2:2014, BS EN 13001-3-1:2012+A1:2013, BS EN 13001-3-2:2014, BS EN 13001-3-4 and DD CEN/TS 13001-3-5:2010 supersedes BS 2573-1:1983 and BS 2573-2:1980, which will be withdrawn on publication of all parts of the BS EN 13001 series.

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The UK participation in its preparation was entrusted by Technical Committee MHE/3, Cranes and derricks, to Subcommittee MHE/3/1, Crane design.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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Foreword

This document (EN 13001-3-3:2014) has been prepared by Technical Committee CEN/TC 147 “Cranes — Safety”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2015, and conflicting national standards shall be withdrawn at the latest by April 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

This European Standard is one part of EN 13001, *Cranes — General design*. The other parts are as follows:

— *Part 1: General principles and requirements*

— *Part 2: Load actions*

— *Part 3-1: Limit states and proof of competence of steel structure*

— *Part 3-2: Limit states and proof of competence of wire ropes in reeving systems*

— *Part 3-4: Limit states and proof of competence of machinery*

— *Part 3-5: Limit states and proof of competence of forged hooks*

For the relationship with other European Standards for cranes, see Annex D.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This European Standard has been prepared to provide a means for the mechanical design and theoretical verification of cranes to conform with the essential health and safety requirements. This European Standard also establishes interfaces between the user (purchaser) and the designer, as well as between the designer and the component manufacturer, in order to form a basis for selecting cranes and components.

This European Standard is a type C standard as stated in EN ISO 12100.

The machinery concerned and the extent to which hazards are covered are indicated in the Scope of this European Standard.

When provisions of this type C standard are different from those which are stated in type A or B standards, the provisions of this type C standard take precedence over the provisions of the other standards, for machines that have been designed and built according to the provisions of this type C standard.

1 Scope

This European Standard is to be used together with EN 13001-1 and EN 13001-2 and as such they specify general conditions, requirements and methods to prevent mechanical hazards of wheel/rail contacts of cranes by design and theoretical verification. This European Standard covers requirements for steel and cast iron wheels and is applicable for metallic wheel/rail contacts only.

Roller bearings are not in the scope of this European Standard.

Exceeding the limits of strength is a significant hazardous situation and hazardous event that could result in risks to persons during normal use and foreseeable misuse. Clause 5 to Clause 6 of this European Standard are necessary to reduce or eliminate the risks associated with this hazard.

This European Standard is applicable to cranes, which are manufactured after the date of approval of this European Standard by CEN, and serves as a reference base for product standards of particular crane types.

This European Standard is for design purposes only and should not be seen as a guarantee of actual performance.

EN 13001-3-3 deals only with limit state method in accordance with EN 13001-1.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13001-1, *Cranes - General design - Part 1: General principles and requirements*

EN 13001-2, *Crane safety - General design - Part 2: Load actions*

EN ISO 6506-1, *Metallic materials - Brinell hardness test - Part 1: Test method (ISO 6506-1)*

EN ISO 12100, *Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO 12100)*

ISO 4306-1, *Cranes — Vocabulary — Part 1: General*

ISO 12488-1:2012, *Cranes — Tolerances for wheels and travel and traversing tracks — Part 1: General*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 12100, ISO 4306-1 and the following apply.

3.1.1
wheel
rolling component in a rolling contact enabling relative movement between two crane parts

EXAMPLE Crane travel wheels, trolley traverse wheels, guide rollers and wheels/rollers supporting slewing structures.

Note 1 to entry: Roller elements in rolling bearings are not considered as wheels.

3.1.2
unit-conform hardness
Brinell hardness HBW of the material given with the unit of the modulus of elasticity

EXAMPLE A Brinell hardness HBW of 300 results in a unit-conform hardness HB = 300 N/mm².

Note 1 to entry: Annex B provides a table of hardness conversion for different methods of hardness measurements.

3.2 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations given in Table 1 apply.

Table 1 — Symbols and abbreviations

Symbols, abbreviations	Description
b	Effective load-bearing width
D_w	Wheel diameter
E_m	Equivalent modulus of elasticity
E_r	Modulus of elasticity of the rail material
E_w	Modulus of elasticity of the wheel material
F	Wheel load
$F_{Rd,s}$	Limit design contact force
$F_{Sd,s}$	Design contact force
$F_{Rd,f}$	Limit design contact force for fatigue
$F_{Sd,f}$	Maximum design contact force for fatigue
$F_{Sd,f,i}$	Design contact force for fatigue in contact (i)
$F_{Sd0,s}$	Non-factored design contact force (calculated with partial safety factors set to 1)
F_u	Reference contact force
f_f	Factors of further influences in fatigue
f_{f1}	Decreasing factor for edge pressure in fatigue
f_{f2}	Decreasing factor for non-uniform pressure distribution in fatigue
f_{f3}	Decreasing factor for skewing in fatigue
f_{f4}	Decreasing factor for driven wheels in fatigue
f_1	Decreasing factor for edge pressure
f_2	Decreasing factor for non-uniform pressure distribution
f_y	Yield stress or 0,2 % proof stress of the material, prior to surface hardening when this process is applied. In the text of the standard only the term yield stress is used to denote either.
HBW	Brinell hardness
HB	Unit-conform hardness, [N/mm²]
i	Index of a rolling contact

Symbols, abbreviations	Description
i_D	Number of rolling contacts at reference point
i_{tot}	Total number of rolling contacts during the design life of wheel or rail
m	Slope constant of log F/log N-curve for rolling contacts
k_c	Contact force spectrum factor
r_k	Radius of the crowned rail head or the second wheel radius
r_3	Radius of the wheel or rail edge
s_c	Contact force history parameter
S_c	Classes of contact force history parameter
w	Width of projecting, non-contact area
z_{ml}, z_{mp}	Depth of maximum shear stress for line and point contact case, respectively
α	Skew angle
α_g	Part of the skew angle α due to the slack of the guide
α_t	Part of the skew angle α due to tolerances
α_w	Part of the skew angle α due to wear
γ_{cf}	Contact resistance factor
γ_m	General resistance coefficient; γ_m = 1,1
γ_n	Risk coefficient
γ_p	Partial safety factors
ν	Radial strain coefficient (ν = 0,3 for steel)
ν_c	Relative total number of rolling contacts
ϕ_i	Dynamic factors (see EN 13001-2)

4 General

4.1 General principles

The proof of competence for static strength and fatigue strength shall be fulfilled for the selection of wheel and rail combination. In the proof of competence for static strength the material properties of the weaker party (wheel or rail) shall be applied, whereas the proof of competence for fatigue strength (rolling contact fatigue, RCF) shall be conducted separately to each party, applying its specific material property and number of rolling contacts.

The proof shall be applied to all arrangements in cranes, where a wheel/rail type of rolling contact occurs, e.g. crane travel wheels, trolley traverse wheels, guide rollers and wheels/rollers supporting slewing structures. The term wheel is used throughout the document for the rolling party in a contact.

NOTE For recommendations on dimensions of wheel flanges, refer to EN 13135, Annex B.

The proof of competence criteria in Clause 5 and Clause 6 are based upon Hertz pressure on the contact surface and the shear stress below the surface due to the wheel/rail contact.

Some formulae used for calculations within this document refer to a so called “unit-conform hardness” HB based on the Brinell hardness HBW given as a value without unit according to EN ISO 6506-1. The unit of HB shall match with the unit of the modulus of elasticity used in the calculation. Using SI-units, the unit-conform hardness is given by:

$$HB = HBW \cdot \frac{N}{\text{mm}^2} \tag{1}$$

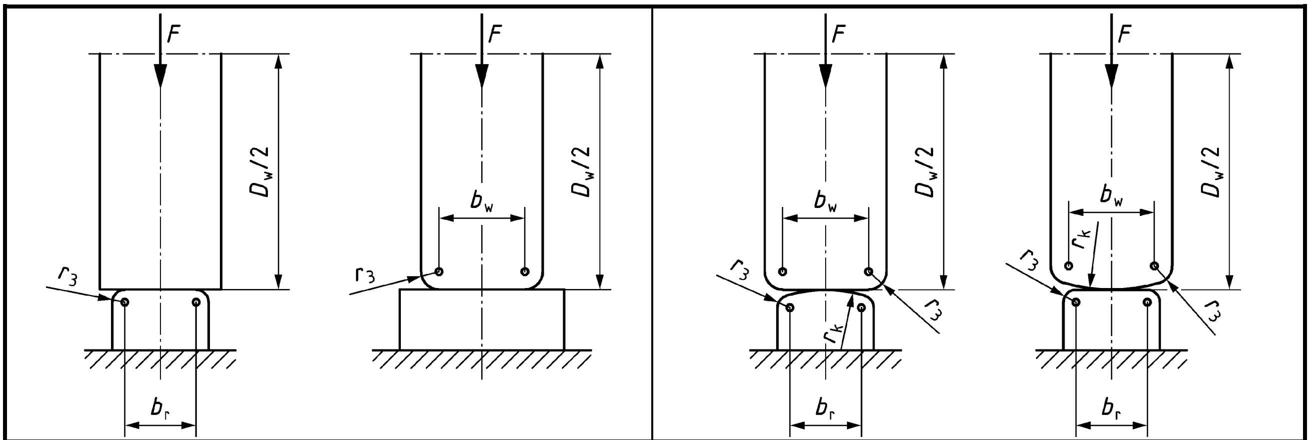
where

HB is the unit-conform hardness;

HBW is the value of the Brinell hardness.

4.2 Line and point contact cases

There are principally two different contact cases in typical designs of crane wheels and rails: a line contact and a point contact (see Figure 1). With the crown radius r_k relatively large in relation to width of the wheel and rail, as is the case for cranes, point contact even for new installations will be rapidly transformed into line contact. Figure 1 shows the conditions of the point contacts, which can be considered as line contacts, for the proof of both static and fatigue strength.



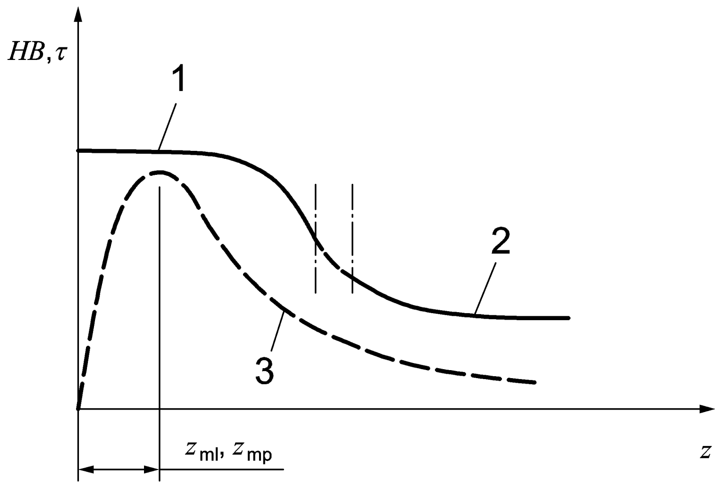
a) Line contact	**b) Point contact**
	Point contact cases, where $r_k \leq 5 \times \min[b_r; b_w]$ are outside the scope of this standard. In cases, where $r_k > 200 \times \min[b_r; b_w]$, the requirements given for line contact shall be applied.
The effective contact widths (b_w, b_r) are determined by deducting from the material width of wheel/rail the effect of corner radius equal to $2 \times r_3$.	

Figure 1 — Contact cases

4.3 Hardness profile below contact surface

It shall be ensured that the hardness achieved extends into the material deeper than the depth of maximum shear, preferably twice this depth. The hardness value can be obtained using the ultimate strength of the material and appropriate conversion tables. For commonly used materials, see Annex B.

Special care shall be taken with surface hardening and the depth zone, to ensure that the hardness profile does not drop below the shear profile (see Figure 2).



Key

z	depth
z_{ml}, z_{mp}	depths of maximum shear stress for line and point contact case respectively
HB	unit-conform hardness
1	hardness, the surface hardened zone
2	hardness, the natural hardness of the material
3	shear stress τ due to contact force

Figure 2 — Hardness and shear stress versus depth

The depth of maximum shear for line contact cases shall be calculated as:

$$z_{ml} = 0{,}50 \times \sqrt{F_{Sd0,s} \times \frac{\pi \times D_w \times \left(1 - \nu^2\right)}{b \times E_m}} \tag{2}$$

and for point contact cases this shall be calculated as:

$$z_{mp} = 0{,}68 \times \sqrt[3]{\frac{F_{Sd0,s}}{E_m} \times \frac{1 - \nu^2}{\left(\frac{2}{D_w} + \frac{1}{r_k}\right)}} \tag{3}$$

where

$F_{Sd0,s}$ is the maximum, non-factored design contact force within the Load Combinations A to C in accordance with EN 13001-2;

E_m is the equivalent modulus of elasticity, see 4.4.

The contact surface of the wheel rim on hardened wheels should be finished to a surface quality R_a 6,3 µm or better in accordance with EN ISO 4287.

4.4 Equivalent modulus of elasticity

The equivalent modulus of elasticity shall be calculated by Formula (4), which covers also the case where the elastic modulus of wheel and rail are different:

$$E_m = \frac{2 \cdot E_w \cdot E_r}{E_w + E_r} \tag{4}$$

where

E_m is the equivalent modulus of elasticity;

E_w is the modulus of elasticity of the wheel;

E_r is the modulus of elasticity of the rail.

Values of the elastic moduli for selected materials are given in Table 2.

Table 2 — Values of elastic modulus

Wheel/rail material	**Modulus of elasticity** N/mm^2
Steel	210 000
Cast iron	176 000
Steel/cast iron-combination	E_m = 191 500

5 Proof of static strength

5.1 General

For the proof of static strength of wheel/rail contacts, it shall be proven that for all relevant load combinations of EN 13001-2:

$$F_{Sd,s} \leq F_{Rd,s} \tag{5}$$

where

$F_{Sd,s}$ is the design contact force;

$F_{Rd,s}$ is the limit design contact force.

5.2 Design contact force

The design contact force $F_{Sd,s}$ of wheel/rail contacts shall be calculated for all relevant load combinations of EN 13001-2, taking into account the respective dynamic factors ϕ_i, partial safety factors γ_p and where required the risk coefficient γ_n. The most unfavourable load effects from possible positions of the mass of the hoist load and crane configurations shall be taken into account.

5.3 Static limit design contact force

5.3.1 General

The static limit design contact force $F_{Rd,s}$ is specified as a force to cause a permanent radial deformation of 0,02 % of the wheel radius.

The static limit design contact force depends on:

— materials properties (modulus of elasticity, yield stress and hardness) of wheel and rail;

— geometry (radii of wheel and rail);

— further influences (stiffness, edge effects).

Cases where $r_k \leq 5 \times \min\left[b_r; b_w\right]$ (see Figure 1) fall outside the method given in this standard. In those cases, the calculation of the limit design force shall be calculated using general Hertzian theory.

5.3.2 Calculation of the limit design force

The static limit design contact force shall be calculated separately both for wheel and rail, using either Formula (6) or Formula (7). For the proof of competence in accordance with Formula (5) the value taken for $F_{Rd,s}$ shall be the smaller of the values obtained for the wheel and the rail. The effective load-bearing width is the same in both calculations.

Formula (6) applies for non-surface hardened materials only, e.g. materials as cast, forged, rolled or quenched and tempered.

$$F_{Rd,s} = \frac{(7 \times HB)^2}{\gamma_m} \times \frac{\pi \times D_w \times b \times \left(1 - \nu^2\right)}{E_m} \times f_1 \times f_2 \tag{6}$$

Formula (7) applies for surface hardened materials, e.g. flame or induction hardened, provided surface hardness is equal to or greater than HB = 0,6 × f_y, and the depth of hardened layer meets the requirements of 4.3.

$$F_{Rd,s} = \frac{\left(4{,}2 \times f_y\right)^2}{\gamma_m} \times \frac{\pi \times D_w \times b \times \left(1 - \nu^2\right)}{E_m} \times f_1 \times f_2 \tag{7}$$

where

$F_{Rd,s}$	is the static limit design contact force;
E_m	is the equivalent modulus of elasticity;
ν	is the radial strain coefficient (ν = 0,3 for steel);
D_w	is the wheel diameter;
b	is the effective load-bearing width taken as $b = \min\left[b_r ; b_w\right]$, see Figure 1;
HB	is the unit-conform hardness (see 3.1.2) based on the natural hardness of the material, at the depth of maximum shear, see Annex A;

γ_m is the general resistance coefficient; $\gamma_m = 1{,}1$;

f_y is the yield stress of the material below the hardened surface, i.e. the natural yield stress of the material prior to the surface hardening process, see Annex A;

f_1 is the decreasing factor for edge pressure. For line contact, see 5.3.3; for point contact cases the factor f_1 may be set to 1,0;

f_2 is the decreasing factor for non-uniform pressure distribution. For line contact, see 5.3.4; for point contact cases the factor f_2 may be set to 1,0.

5.3.3 Edge pressure in line contact

Formulae for the limit design contact force in the line contact case are derived from the case of two bodies in contact of the same width. Factor f_1 as given in Table 3 introduces a correction to the limit design contact force for the situation when the two bodies are of unequal width (see Figure 3). Where the rail is wider than the wheel, the radius of the edge (r_3) shall be taken as that of the wheel.

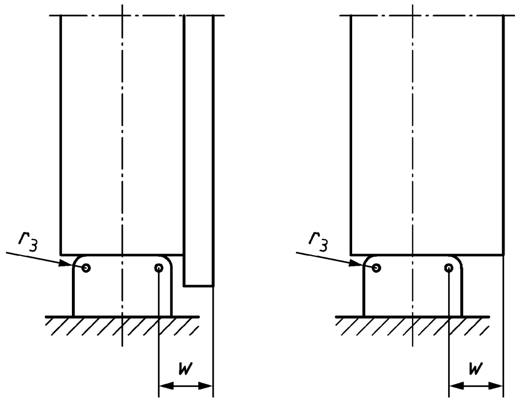


Figure 3 — Edge pressure

Table 3 — Factor f_1 for edge pressure in line contact

Ratio r_3/w	Factor f_1
$r_3/w \le 0{,}1$	0,85
$0{,}1 < r_3/w < 0{,}8$	$\left[0{,}58 + 0{,}15\left(r_3/w\right)\right]/\,0{,}7$
$r_3/w \ge 0{,}8$	1,0

where
w is the width of the projecting non-contact area and
r_3 is the radius of the edge of the non-projecting part (wheel or rail).

5.3.4 Non-uniform pressure distribution in line contact

An ideal uniform distribution across the tread of the wheel in the line contact case is dependent upon sufficient elasticity of the rail fixing or its support and/or wheels with self-aligning suspension. Otherwise, deformation of the crane structure (e.g. bending of main girders) or tolerances in rail alignment result in non-uniform pressure distribution, decreasing the limit design contact force. This effect shall be taken into account by factor f_2, given in Table 4.

Table 4 — Factor f_2 for non-uniform pressure distribution in line contact

	Tolerance class of ISO 12488-1			
	1	**2**	**3**	**4**
Wheels with self-aligning mounting	1,0	1,0	0,95	0,9
Non-aligning wheel mounting, rail mounted on elastic support	0,95	0,9	0,85	0,8
Non-aligning wheel mounting, rail mounted on rigid support	0,9	0,85	0,8	0,7

6 Proof of fatigue strength

6.1 General

The proof of competence for fatigue strength of wheels and rails shall be carried out in accordance with the principles of EN 13001-1 and EN 13001-2. The wheels and the rails shall have a specified design life, proportionate to that of the related crane or hoist. The proof covers hazards related to Rolling Contact Fatigue, i.e. surface cracking and pitting of wheels and rails. Guidance for selection of wheel/rail materials to avoid excessive wear is given in Annex C.

For the proof of fatigue strength of wheel/rail contacts it shall be proven that for each wheel and for all points on the rails

$$F_{Sd,f} \leq F_{Rd,f} \qquad (8)$$

where

$F_{Sd,f}$ is the maximum design contact force for fatigue;

$F_{Rd,f}$ is the limit design contact force for fatigue.

6.2 Design contact force

The design contact force $F_{Sd,f}$ shall be calculated for the regular loads (load combinations A of EN 13001-2) with the risk coefficient included, and with all dynamic factors $\phi_i = 1$ and all partial safety factors $\gamma_p = 1$. The skewing forces acting on guide rollers shall be considered as regular loads.

6.3 Limit design contact force

6.3.1 Basic formula

The limit design contact force $F_{Rd,f}$ shall be calculated separately both for wheel and for rail by

$$F_{Rd,f} = \frac{F_u}{\gamma_{cf} \times \sqrt[m]{s_c}} \times f_f \qquad (9)$$

where

F_u is the reference contact force;

s_c is the contact force history parameter, calculated separately for wheel and rail;

γ_{cf} is the contact resistance factor for fatigue γ_{cf} = 1,1;

f_t is the factor of further influences;

m is the exponent for wheel/rail contacts, m = 10/3 = 3,33.

6.3.2 Reference contact force

The limit design contact force of a wheel or rail subjected to rolling contact fatigue is characterised by the reference contact force F_u, which represents the fatigue strength under $6{,}4 \times 10^6$ rolling contacts under constant contact force and a probability of survival of 90 % (i. e. avoiding cracks, pitting, excessive wear).

The reference contact force shall be calculated separately both for wheel and for rail. The material property used in calculation shall be that specific for the party calculated; either wheel or rail. The effective load-bearing width is the same in both calculations.

Formula (10) applies for non-surface hardened materials only, e.g. materials as cast, forged, rolled or quenched and tempered.

$$F_u = (3{,}0 \times HB)^2 \times \frac{\pi \times D_w \times b \times (1 - \nu^2)}{E_m} \quad (10)$$

Formula (11) applies for surface hardened materials, e.g. flame or induction hardened, provided surface hardness is equal to or greater than $HB = 0{,}6 \times f_y$, and the depth of hardened layer meets the requirements of 4.3.

$$F_u = (1{,}8 \times f_y)^2 \times \frac{\pi \times D_w \times b \times (1 - \nu^2)}{E_m} \quad (11)$$

where

E_m is the equivalent modulus of elasticity;

ν is the radial strain coefficient (ν = 0,3 for steel);

D_w is the wheel diameter;

b is the effective load-bearing width taken as $b = \min[b_r; b_w]$, see Figure 1;

HB is the unit-conform hardness, based on the natural hardness of the material, at the depth of maximum shear, see Annex A;

f_y is the yield stress of the material below the hardened surface, i.e. the natural yield stress of the material prior to the surface hardening process, see Annex A.

Cases where $r_k \leq 5 \times \min[b_r; b_w]$ (see Figure 1) fall outside the method given in this standard. In those cases, the calculation of the limit design force shall be calculated using general Hertzian theory.

6.3.3 Contact force history parameter

In analogy to stress history parameter (see EN 13001-1), the contact force history parameter shall be calculated by

$$s_c = k_c \cdot v_c \tag{12}$$

where

k_c is the contact force spectrum factor;

v_c is the relative total number of rolling contacts.

The contact force history parameter describes the fatigue effect of the specified use in terms of rolling contacts in a particular wheel/rail pair.

6.3.4 Contact force spectrum factor

The contact force spectrum factor k_c shall be calculated by

$$k_c = 1/i_{tot} \cdot \sum_{i=1}^{i_{tot}} \left(\frac{F_{Sd,f,i}}{F_{Sd,f}} \right)^m \tag{13}$$

where

i is the index of a rolling contact with $F_{Sd,f,i}$

i_{tot} is the total number of rolling contacts during the design life of wheel or rail,

$F_{Sd,f,i}$ is the design contact force for fatigue in a contact i;

$F_{Sd,f}$ is the maximum of all forces $F_{Sd,f,i}$;

m is the exponent for wheel/rail contacts, m = 10/3 = 3,33.

NOTE Formula (13) implies that the rolling contacts are counted individually.

6.3.5 Counting of rolling contacts

The total number of rolling contacts i_{tot} shall be calculated separately for wheel and for rail. For a wheel, one revolution is equivalent to one rolling contact, whereas for a selected point on the rail the passing over by any wheel represents one rolling contact. In cases where the wheel is not rolling but the load is fluctuating in cycles, one load cycle shall be considered as one rolling contact.

Formula (14) and Formula (15) show the calculation for i_{tot} for a work cycle comprising a two-way motion over the point of the rail under consideration, i.e. a work cycle with the laden crane passing over the point in one direction and unladen on the return part of the work cycle.

For a running wheel:

$$i_{tot} = \frac{1}{l_w} \cdot \frac{2 \cdot \bar{x} \cdot C}{\pi \cdot D_w} \tag{14}$$

where

$\bar{x}$ is the average displacement of the related crane motion, see EN 13001-1;

C is the total number of working cycles during the design life of the crane, see EN 13001-1;

l_w is the design number of wheel sets used during the design life of the crane (i.e. number of wheel sets replacements + 1); for guidance see Table 5;

D_w is the wheel diameter.

For a point on the rail with wheels passing over:

$$i_{tot} = 2 \cdot n_w \cdot C \qquad (15)$$

where

n_w is the total number of wheels of the crane passing over the point under consideration on the particular rail.

Table 5 — Guidance for selection of design number of wheel sets

Class U of total number of working cycles (EN 13001-1**)**	**Number of wheel sets l_w**
U0 to U2	1
U3 to U6	1–2
U7 to U9	1–3

6.3.6 Relative total number of rolling contacts

The relative total number of rolling contacts v_c shall be calculated by

$$v_c = \frac{i_{tot}}{i_D} \qquad (16)$$

where

i_{tot} is the total number of rolling contacts during the design life of wheel or rail;

i_D is the number of rolling contacts at reference point, $i_D = 6{,}4 \cdot 10^6$.

6.3.7 Classification of contact force history parameter

In the proof of competence calculations for a particular use specified in accordance with EN 13001-1, the contact force history parameter shall be determined by Formula (12).

Wheels and rails may be assigned to classified sets of values of contact force history parameters. Table 6 shows a recommended series of parameters and the symbols of the related classes. Where classification is referred to, compatibility between the selected S_c-class and the specified use shall be shown in the proof of competence calculations.

Table 6 — Classes S_c of contact force history parameter s_c

Class	S_c0	S_c1	S_c2	S_c3	S_c4	S_c5	S_c6	S_c7	S_c8	S_c9
s_c	0,008	0,016	0,032	0,063	0,125	0,25	0,5	1,0	2,0	4,0

NOTE Change of wheel diameter changes the s_c-parameter and might change the S_c-class.

6.4 Factors of further influences

6.4.1 Basic formula

The factor f_f takes into account further influences on the limit design contact force and shall be calculated as follows:

$$f_f = f_{f1} \cdot f_{f2} \cdot f_{f3} \cdot f_{f4} \quad (17)$$

where

f_{f1} to f_{f4} are the factors of influences as given in 6.4.2 to 6.4.5.

6.4.2 Edge pressure for fatigue

Due to lateral movements of wheels, the edge pressure effect on the wider party (wheel or rail) may be neglected and the factor f_{f1} is set to 1. For the narrower party with the edge radius r_3 (see Figure 3) applies the following:

$$f_{f1} = f_1 \quad (18)$$

where

f_1 is the factor for edge pressure as given in 5.3.3.

6.4.3 Non-uniform pressure distribution for fatigue

For the proof of fatigue strength the non-uniform pressure distribution may be neglected and f_{f2} is set to 1.

6.4.4 Skewing

A skewing wheel causes wear of wheel and rail and thus shortens the useful life. The wear is increased over-proportionally in relation to the skew angle α. This effect shall be taken into account by factor f_{f3}.

$f_{f3} = 1$ for $\alpha \le 0{,}005$ rad

$$f_{f3} = \sqrt[3]{\frac{0{,}005}{\alpha}} \quad \text{for } \alpha > 0{,}005 \text{ rad} \quad (19)$$

where

$\alpha = \alpha_g + \alpha_w + \alpha_t$ is the skew angle of the crane in radians, calculated in accordance with EN 13001-2.

The part of the skew angle due to tolerances α_t shall be chosen from the Table 7 according to the tolerance class.

Table 7 — Design values of alignment angle of a single wheel

	Tolerance class of ISO 12488-1			
	1	**2**	**3**	**4**
Angle α_t [rad]	0,001 5	0,002 5	0,003 5	0,004 5

6.4.5 Mechanical drive factor

In an unclean environment, the mechanical abrasion effects on the driven wheels shall be taken into account by factor f_{f4}:

f_{f4} = 0,95 for driven wheels in environment with abrasive particles (20)

f_{f4} = 1,0 for non-driven wheels or wheels in environment without abrasive particles.

Annex A
(informative)

Strength properties for a selection of wheel and rail materials

Table A.1 — Wheel and rail materials and their strength properties

Wheel materials					
Designation	**Standard**	**Material No.**	**Delivery state**	**Ultimate strength f_u** N/mm²	**Design hardness** *HBW*
GE 300	EN 10293	1.0558	+N	520	155
EN-GJS 600-3	EN 1563	0.7060	as cast	600	210 (***)
EN-GJS 700-2	EN 1563	0.7070	as cast	700	245 (***)
25CrMo4	EN 10083-3	1.7218	+QT	650	190
34CrMo4	EN 10083-3	1.7220	+QT	700	210
42CrMo4	EN 10083-3	1.7225	+QT	750	225
33NiCrMoV14-5	EN 10250-3	1.6956	+QT	1 000	295
Wheel materials, surface hardened					
Designation	**Standard**	**Material No.**	**Delivery state**	**Design yield stress f_y** N/mm²	**Minimum surface hardness** *HBW*
42CrMo4	EN 10083-3	1.7225	+N , surface hardened	420	252 (*)
Rail materials					
Designation	**Standard**	**Material No.**	**Delivery state**	**Ultimate strength f_u** N/mm²	**Design hardness** *HBW*
S235 (**)	EN 10025-2	–	+N	360	125 (***)
S275 (**)	EN 10025-2	–	+N	410	145 (***)
S355 (**)	EN 10025-2	–	+N	520	175 (***)
S690Q	EN 10025-6	1.8928	+QT	760	225
C35E	EN 10083-2	1.1181	+N	520	155
C55	EN 10083-2	1.0535	+N	640	190
R260Mn	EN 13674-1	1.0624	+N	870	260

Key

+N Normalized

+QT Quenched and tempered

(*) Hardness to be specified based on the hardening process and required depth.

(**) Table values are valid to any of the quality grades JR, J0, J2 and K2.

(***) The values deviate from the minimum given in the material standard due to work hardening occurring in service from rolling contact [16].

Annex B
(informative)

Conversion table of hardnesses

Table B.1 — Conversion table of hardnesses

Hardness						**Hardness**				
HV	*HBW*	*HRA*	*HRB*	*HRC*	*HRD*	*HV*	*HBW*	*HRA*	*HRC*	*HRD*
120	**114**		67			350	**332**	68,1	35,5	51,9
130	**123**		71			360	**342**	68,7	36,6	52,8
140	**133**		75,1			370	**351**	69,2	37,7	53,8
150	**142**		78,8			380	**361**	69,8	38,8	54,4
160	**152**		82,1			390	**370**	70,3	39,8	55,2
170	**161**		85			400	**380**	70,8	40,8	56
180	**171**		87,3			410	**389**	71,4	41,8	56,8
190	**180**		89,6			420	**399**	71,8	42,7	57,5
200	**190**		91,8			430	**409**	72	43,6	58,2
210	**199**		93,7			440	**418**	72,3	44,5	58,8
220	**209**		95,5			450	**423**	73,3	45,3	59,4
230	**218**					460	**432**	73,6	46,1	60,1
240	**228**	60,7		20,3	40,3	470	**442**	74,1	46,9	60,7
250	**235**	61,6		22,2	41,7	480	**450**	74,5	47,7	61,3
260	**247**	62,4		24	43,1	490	**456**	74,9	48,4	61,6
270	**256**	63,1		26,6	44,3	500	**466**	75,3	49,1	62,2
280	**266**	63,8		27,1	45,3	510	**475**	75,7	49,8	62,9
290	**275**	64,5		28,5	46,5	520	**483**	76,1	50,5	63,5
300	**285**	65,2		29,8	47,5	530	**492**	76,4	51,1	63,9
310	**294**	65,8		31	48,4	540	**500**	76,7	51,7	64,4
320	**304**	66,4		32,2	49,4	550	**509**	77	52,3	64,8
330	**313**	67		33,3	50,2	560	**517**	77,4	53	65,4
340	**323**	67,6		34,4	51,1	570	**526**	77,8	53,6	65,8

Key

HV is the Vickers hardness;

HBW is the Brinell hardness;

HR is the Rockwell hardness as follows: *HRA*, *HRB*, *HRC*, *HRD*.

Values are based on EN ISO 18265, taken as average of those typical to crane wheel and rail materials. Specific values based on particular delivery condition or heat treatment may be used.

Annex C
(informative)

Examples for wheel/rail material pairs and their wear behaviour

Table C.1 — Material pairs and their wear behaviour

Wheel material	Rail material	Predominantly wearing partner and level of wear	
		wheel	rail
GE 300	C55	=	=
GE 300	R260Mn	**	
EN-GJS 700-2	S235		**
EN-GJS 700-2	S275		**
EN-GJS 700-2	S355		*
EN-GJS 700-2	S690QL	*	
25CrMo4+QT	S355		**
34CrMo4+QT	S355		**
34CrMo4+QT	C35E		*
34CrMo4+QT	S690QL	=	=
42CrMo4+QT	S355		**
42CrMo4+QT	C55	=	=
42CrMo4+QT	R260Mn	*	
33NiCrMoV14-5 Surface hardened	C55		**
33NiCrMoV14-5 Surface hardened	R260Mn		*
42CrMo4 Surface hardened	S355		**
42CrMo4 Surface hardened	C55		***

Key

=	equal wear in wheel and rail
*	light wear
**	moderate wear
***	heavy wear

Annex D
(informative)

Selection of a suitable set of crane standards for a given application

Is there a product standard in the following list that suits the application?	
EN 13000	Cranes — Mobile cranes
EN 14439	Cranes — Safety — Tower cranes
EN 14985	Cranes — Slewing jib cranes
EN 15011	Cranes — Bridge and gantry cranes
EN 13852-1	Cranes — Offshore cranes — Part 1: General purpose offshore cranes
EN 13852-2	Cranes — Offshore cranes — Part 2: Floating cranes
EN 14492-1	Cranes — Power driven winches and hoists — Part 1: Power driven winches
EN 14492-2	Cranes — Power driven winches and hoists — Part 2: Power driven hoists
EN 12999	Cranes — Loader cranes
EN 13157	Cranes — Safety — Hand powered cranes
EN 13155	Cranes — Non-fixed load lifting attachments
EN 14238	Cranes — Manually controlled load manipulating devices
EN 15056	Cranes — Requirements for container handling spreaders

YES

Use it directly, plus the standards that are referred to.

NO

Use the following:	
EN 13001-1	Cranes — General design — Part 1: General principles and requirements
EN 13001-2	Crane safety — General design — Part 2: Load actions
EN 13001-3-1	Cranes — General Design — Part 3-1: Limit states and proof of competence of steel structure
EN 13001-3-2	Cranes — General design — Part 3-2: Limit states and proof of competence of wire ropes in reeving systems
EN 13001-3-3	Cranes — General design — Part 3-5: Limit states and proof of competence of wheel/rail contacts
prEN 13001-3-5	Cranes — General design — Part 3-5: Limit states and proof of competence of forged hooks
EN 13135	Cranes — Safety — Design — Requirements for equipment
EN 13557	Cranes — Controls and control stations
EN 12077-2	Cranes safety — Requirements for health and safety — Part 2: Limiting and indicating devices
EN 13586	Cranes — Access
EN 14502-1	Cranes — Equipment for the lifting of persons — Part 1: Suspended baskets
EN 14502-2	Cranes — Equipment for the lifting of persons — Part 2: Elevating control stations
EN 12644-1	Cranes — Information for use and testing — Part 1: Instructions
EN 12644-2	Cranes — Information for use and testing — Part 2: Marking

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2006/42/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive Machinery 2006/42/EC.

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements of that Directive and associated EFTA regulations.

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

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[11] EN 10250-3, *Open die steel forgings for general engineering purposes - Part 3: Alloy special steels*

[12] EN 10293, *Steel castings for general engineering uses*

[13] EN 13135, *Cranes - Safety - Design - Requirements for equipment*

[14] EN 13674-1, *Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above*

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